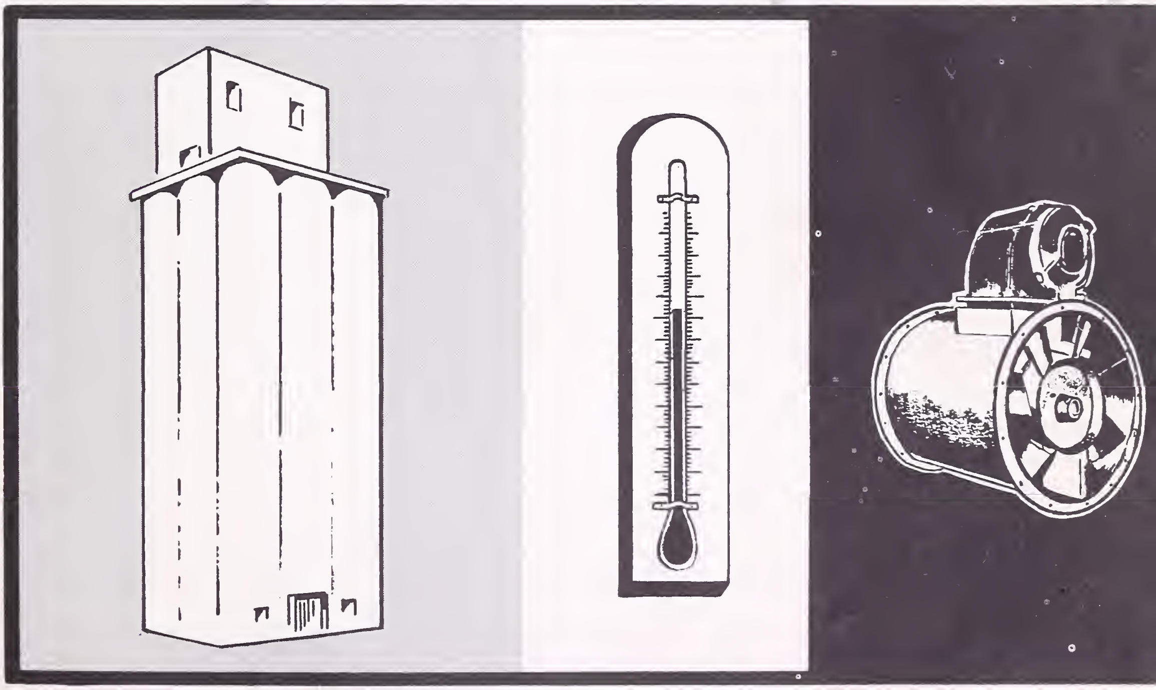
OPERATING GRAIN AERATION SYSTEMS IN THE HARD WINTER WHEAT AREA



Marketing Research Report No. 480

Transportation and Facilities Research Division
Agricultural Marketing Service
U.S. Department of Agriculture
in cooperation with the
Kansas Agricultural Experiment Station

PREFACE

The research on which this report is based is part of a larger project on the aeration of grain in commercial storages. This report discusses methods and procedures for operating grain aeration systems in the Hard Winter Wheat area (Central Plains) of the United States. Similar reports on aeration are planned or have been published for other regions, including the Corn Belt, Southeast, and Southwest. These reports supplement Marketing Research Report No. 178 (rev. Nov. 1960), "Aeration of Grain in Commercial Storage," which emphasizes the design, selection of equipment, and installation of grain aeration systems.

Leo E. Holman, supervisory project leader, Agricultural Marketing Service, contributed valuable suggestions and assisted in preparing the report. Grain storage operators made their facilities available for the tests, and suppliers loaned equipment used in some of the tests.

This research was conducted in cooperation with the Kansas Agricultural Experiment Station. Substantial contributions by the station included space for offices, laboratories, and shops, and measurement of fat acidity, milling and baking tests, and other quality factors of grain samples.

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Washington, D.C. November 1961

DEFINITION OF TERMS

Aeration.—The moving of air through stored grain at low airflow rates, for purposes other than drying, to maintain or improve its value.

Cfm.—Cubic feet per minute, a measure of the volume of air being moved.

Upright storage.—Any storage where the height is greater than the diameter or width. This type of storage is also known as a deep bin, tank, silo, cell, or vertical storage.

Flat storage.—Any storage where the height is less than the diameter or width. These storages are also referred to as horizontal storages.

Level-loading.—Filling flat storages to approximately uniform depth.

Peak-loading.—Filling flat storages so that grain accumulates to a greater depth at the centerline or peak of the building than at the sidewalls. The grain frequently is allowed to assume the angle of repose from the peak to the sidewalls.

Fixed fan system.—An aeration system with a permanently placed fan for each storage or for each duct in a storage.

Manifold system.—An aeration system with a fan connected to two or more storages or ducts through the same manifold.

Portable fan system.—An aeration system with a portable fan movable from bin to bin or from one part of a storage to another part.

Cooling zone.—That portion of the grain mass in a storage where the temperature is falling during aeration.

Cooling stage.—The process of moving a cooling zone entirely through a lot of stored grain.

High limit.—A selected maximum temperature or maximum relative humidity of the outside air, above which the aeration fan is stopped.

Low limit.—A selected minimum temperature or minimum relative humidity of the outside air, below which the aeration fan is stopped.

OPERATING GRAIN AERATION SYSTEMS IN THE HARD WINTER WHEAT AREA

By G. L. Kline and H. H. Converse, *agricultural engineers*, Transportation and Facilities Research Division, Agricultural Marketing Service

SUMMARY

Grain storage operators use aeration systems to maintain quality of grain in storage. With aeration, grain can be cooled to prevent mold growth, control insects, prevent moisture migration, and establish favorable conditions for long-term storage. To help operators plan year-round management of grain in storage, this publication presents fan operating schedules which are primarily for aeration of wheat, but which can be adapted for other grains.

Grain temperatures following aeration in the Hard Winter Wheat area usually are 85° F. in summer, 65° F. in fall, and 45° F. in winter. In aeration applications, air temperatures between a high limit and a low limit (see definition of terms) are selected. High-limit temperatures in the Hard Winter Wheat area usually are 85° F. in the summer, 70° F. in the fall, and 50° F. in the winter. Low-limit temperatures are not used in the summer and fall. For winter aeration, low-limit temperatures selected are dependent on the available airflow rate. Satisfactory high limits for relative humidity are 90 percent in the summer and fall and 80 percent in the winter. Automatic controls are essential to most aeration systems, to restrict fan operation to periods when air temperature and relative humidity are within the selected range.

Weather records were analyzed to find the number of hours available for fan operation. Selected temperature and relative humidity limits were evaluated for six locations in the Hard Winter Wheat area. The hours available were recorded for each month during a 10-year period, 1950 through 1959.

The time required to cool grain was determined from aeration tests. For example, at an airflow rate of 1/20 cfm per bushel, the basic time required to move a cooling zone through grain was 160 hours in the summer, 220 hours in the fall, and 310 hours in the winter.

Recommended fan operating schedules for aeration in the Hard Winter Wheat area are given for upright storages and for flat storages. Information presented includes temperature and relative humidity limits for each season of the year, and the approximate fan operation time required to complete each aeration stage. The operator can use this information for planning the operation of the aeration system and setting automatic controls.

Typical costs of electric power for aerating wheat at 1/30 cfm per bushel in upright storage are: summer stage, 0.07 cent per bushel; fall stage, 0.095 cent per bushel; winter stage, 0.135 cent per bushel; total cost for three stages, 3/10 cent per bushel. Aeration in flat storage at 1/15 cfm per bushel costs about half as much as aerating upright storages at 1/30 cfm per bushel.

Grain storage operators can use aeration systems for special purposes in addition to regularly scheduled cooling of grain in storage. Special uses include (1) storing grain with a moisture content slightly above safe storage level, (2) holding wet grain for brief periods, (3) emergency cooling, (4) removing odors, and (5) applying fumigants. Research tests were conducted to obtain information about these uses and about certain operating problems reported by grain elevator managers. Results of the tests serve as a background for operating suggestions presented in the report.

PURPOSE OF STUDY

Many aeration systems have been installed in commercial grain storages since 1955. Operators have had little information to guide them in using the systems to best advantage. The objective of this report is to describe effective methods of using aeration systems to maintain the market quality of grain.

The following sections present specific recommendations for aeration of wheat with less than 13 percent of moisture in upright and flat storages in the Hard Winter Wheat area (the Central Plains area of Kansas, Nebraska, Oklahoma, eastern Colorado, western Missouri, and the Texas Panhandle). Upright and flat storages are illustrated in figures 1 and 2.

Suggestions for aerating wheat with more than 13 percent of moisture are given in the section on Aerating for Special Purposes. Suggestions also are given for adapting the recommendations for aerating wheat to other grains.

BN–13325

FIGURE 1.—*Manifold aeration system for upright storage, with one fan for eight bins. Hays, Kans., October 1959.*

BN–13326

FIGURE 2.—*Aeration system for flat storage. Fixed fans at each end of the building, with two ducts running lengthwise. Hutchinson, Kans., January 1960.*

BACKGROUND

Aeration systems designed and installed according to principles set forth in "Aeration of Grain in Commercial Storages," published by the USDA (*4*),[1] have proved entirely satisfactory in the Hard Winter Wheat area. Aeration tests conducted in commercial grain elevators equipped with these systems provide the basis for recommendations presented here. The tests were performed primarily in Kansas starting in 1955. The experiences of grain elevator operators using aeration systems are also incorporated in the recommendations.

Aeration tests in upright storages were made in bins of different heights and diameters, with flat bottoms and hopper bottoms, with different types of aeration systems, and with a range of airflow rates. In most tests, the storage period was approximately 1 year, starting with new harvest grain. In some tests, observations were continued through a second year.

Observations were made in flat storages with grain both level-loaded and peak-loaded. The aeration systems included ducts installed lengthwise as well as crosswise of the buildings, and combinations of main and lateral aeration ducts in various arrangements. Grain temperatures and fan operation data recorded by elevator managers also were used in evaluating the many types of aeration systems in flat storages.

The tests included wheat with different initial moisture, temperature, and prestorage treatments. The following methods of operating aeration systems were tested: Continuous operation, multiple-stage and single-stage operation, and different schedules of air temperature and relative humidity limits. Fans were regulated by automatic controls. Recorders were used to collect information about outside air temperature, relative humidity, and the hours of fan operation. Market quality of the grain was determined from composite samples taken before and after storage, and from surface probe samples taken at intervals during the storage year. Quality measurements included official grade, germination, fat acidity, milling and baking tests, and X-ray examination for insect infestation. Grain temperatures were recorded throughout the storage year using temperature cables spaced throughout the grain mass. Operating costs for different types of systems were determined.

PURPOSES OF AERATION

Desirable conditions for maintaining grain quality in storage are measured in terms of grain temperature, grain moisture, and length of time in storage. Similar criteria are applied to evaluate the desirable characteristics of aeration. Other criteria considered include management of the storage to provide the lowest cost for equipment, labor, and operating expenses. Some of the characteristics most desired in aeration are discussed in this section.

COOLING TO PREVENT MOLD

As soon as possible after grain is placed in storage it should be cooled to a temperature at which molds and fungi are not active. Most grain molds grow slowly or not at all below 70° F. in wheat with 13 percent moisture or less (*9*).

[1] Italic numbers in parentheses refer to items in the Literature Cited, p. 20.

COOLING TO CONTROL INSECTS (*10, 2*)

Activity and reproduction of stored-grain insects decrease at low grain temperatures. At 70° F. and higher, insect populations increase rapidly and may damage stored grain severely. At 60° F. and below, insect reproduction is stopped, or nearly so. Most insect pests of stored grain are not active at temperatures below 45° to 50° F. Many stored-grain insects die when temperatures are 40° F. and below for long periods. Some of the more destructive grain insects die in less than 1 month when exposed to temperatures of 35° F. and below. The granary weevil, cadelle, and the moths withstand this low temperature for longer periods.

UNIFORM TEMPERATURES TO PREVENT MOISTURE MIGRATION

Moisture moves from grain in one part of a bin to other grain when a difference in temperature exists. Most grain spoilage occurs when moisture moves from the warm center mass to cold grain at the surface during the fall and winter. Maintaining uniform temperature throughout the grain mass will prevent moisture migration.

To establish uniform grain temperatures with aeration, air is usually moved downward through the bin. Introducing the cold air over the cold surface grain prevents condensation. The downward movement counteracts the natural tendency for warm air to move upward to the cold surface grain, also preventing condensation.

MINIMUM CHANGE IN GRAIN MOISTURE DURING COOLING

Operation of aeration systems must be controlled to prevent grain moisture from rising above the safe storage level. The effect of the normal range of air relative humidities, and the lesser effect of temperature, on the equilibrium moisture content of grain have been recorded (*1*). In aerated bins, the moisture of the grain near the surface will tend to come to equilibrium with the average relative humidity and temperature of the intake air. Therefore, grain should not be aerated when outside air is very moist.

Conversely, for wheat with a safe storage moisture below 13 percent, a decrease in moisture during aeration is undesirable because it will be reflected as a loss in weight or shrinkage under present market practices. Grain always loses a little moisture when it is cooled by aeration. The operating schedule selected should provide for the least moisture removal consistent with accomplishing the desired cooling.

UNIFORM MOISTURE THROUGHOUT BULK

Pockets of high-moisture grain are often a source of difficulty in storing grain. Aeration can help to establish and keep uniform moisture throughout the grain bulk, but airflow rates used in aeration are too low to dry layers or large pockets of high-moisture grain. Aeration probably eliminates small pockets of high moisture and hastens moisture transfer in blends of grains of different moisture.

Mixing or blending grain during filling of an aerated bin is recommended to avoid pockets of high moisture. This report gives no specific operation schedule to equalize moisture in the grain bulk. Additional investigation is needed.

RAPID COOLING

Aeration should begin as early in the storage year as possible. For rapid cooling of grain and efficient use of aeration equipment, the schedule selected should permit fans to operate for an average of 8 hours or more daily. Once cooling has been started, the cooling zone should be moved entirely through the grain.

MANAGING THE GRAIN STORAGE

The grain elevator manager must consider the aeration requirements for the entire storage. For each season of the year, the calendar time available for cooling must be considered. The operating schedule should allow for cooling all of the grain in the storage. Advance planning is particularly important for manifold systems and portable fan systems in which only a part of the storage is aerated at one time. These systems should be managed so that grain in all bins can be completely cooled, particularly during the winter.

The elevator manager must consider the overall operations of receiving, conditioning, storing, maintaining quality, and shipping grain. The aeration operating schedule should provide for minimum handling of grain from time of receipt until it is shipped. The schedule must be sufficiently flexible to permit aeration of newly received grain, maintenance and repair of aeration equipment, holding high-moisture grain for brief periods, fumigation, and other short-term uses of the aeration equipment.

SIMPLICITY

The aeration operation schedule should be as simple as possible. It should provide for a min-

imum of supervision, changes in control settings, and movement of fans from bin to bin.

The system should be automatically controlled. In many cases, manual operation has not been completely satisfactory. Times for starting and stopping fans may be inconvenient for manual operation and may cause good operating weather to be missed or fans to continue to run during unfavorable weather.

LOW COST

The fewer times each lot of grain is cooled, the lower the operating cost. The schedule should provide the fewest cooling stages consistent with establishing favorable storage conditions. For each cooling stage, the lowest cost results from operating fans no longer than the time required to move a cooling zone through the grain.

SELECTING OPERATING SCHEDULES

Many factors must be considered as a basis for selecting effective operating schedules for aeration systems. Some of these—type of storage, type of aeration system, airflow rate, kind of grain, grain moisture, and desirable storage conditions—are discussed in detail in Marketing Research Report No. 178(*4*).

In this section, we consider five other important factors in the selection of operating schedules: (1) Temperature and relative humidity of intake air; (2) hours available for fan operation; (3) time required to cool grain; (4) automatic control of operation; and (5) cost of operation.

Typical cooling of wheat by three-stage, two-stage, and single-stage aeration is illustrated in figure 3. In the summer, new harvest wheat with temperatures up to 100° F. or more can be cooled to approximately 85° F. This cooling is not sufficient to stop development of mold and insects but is desirable to establish and maintain uniform temperatures and moistures throughout the bin. In the fall, wheat can be cooled to 60° to 70° F., which is low enough to prevent rapid development of mold. Uniform grain temperatures and moistures are also maintained. In the winter, wheat is cooled to 50° F. or below in all parts of the bin. This temperature restricts mold development and insect activity, and keeps grain temperatures and moistures uniform.

Since atmospheric air is the medium used for cooling grain, the temperature and relative humidity of the air are important in operating aeration systems. Figure 4 shows the changes in air temperature and relative humidity during an average day in each of 4 months—July, October, January, and April—in Wichita, Kans. In addition to the seasonal and daily changes illustrated, the hourly temperatures and relative humidities may vary widely on any day from the average pattern shown.

DESIRABLE TEMPERATURE OF INTAKE AIR

In general, optimum grain temperatures for storage range between 35° and 50° F. These temperatures are low enough to reduce mold development, insect activity, and moisture migration.

Grain at temperatures below 35° F. may be harder to manage than grain at 35° to 50° F. Moisture may condense on cold grain if it is moved in warm weather. Also problems caused by surface moisture buildup may be greater as stored grain warms in the spring and summer. Grain storage operators report some difficulty from moisture condensation in warm grain near the walls of bins that are adjacent to bins of cold aerated grain.

Desirable temperatures for aeration range between a maximum or high-limit temperature and a minimum or low-limit temperature. Fans are operated when the outside air temperature is between the high and low limits.

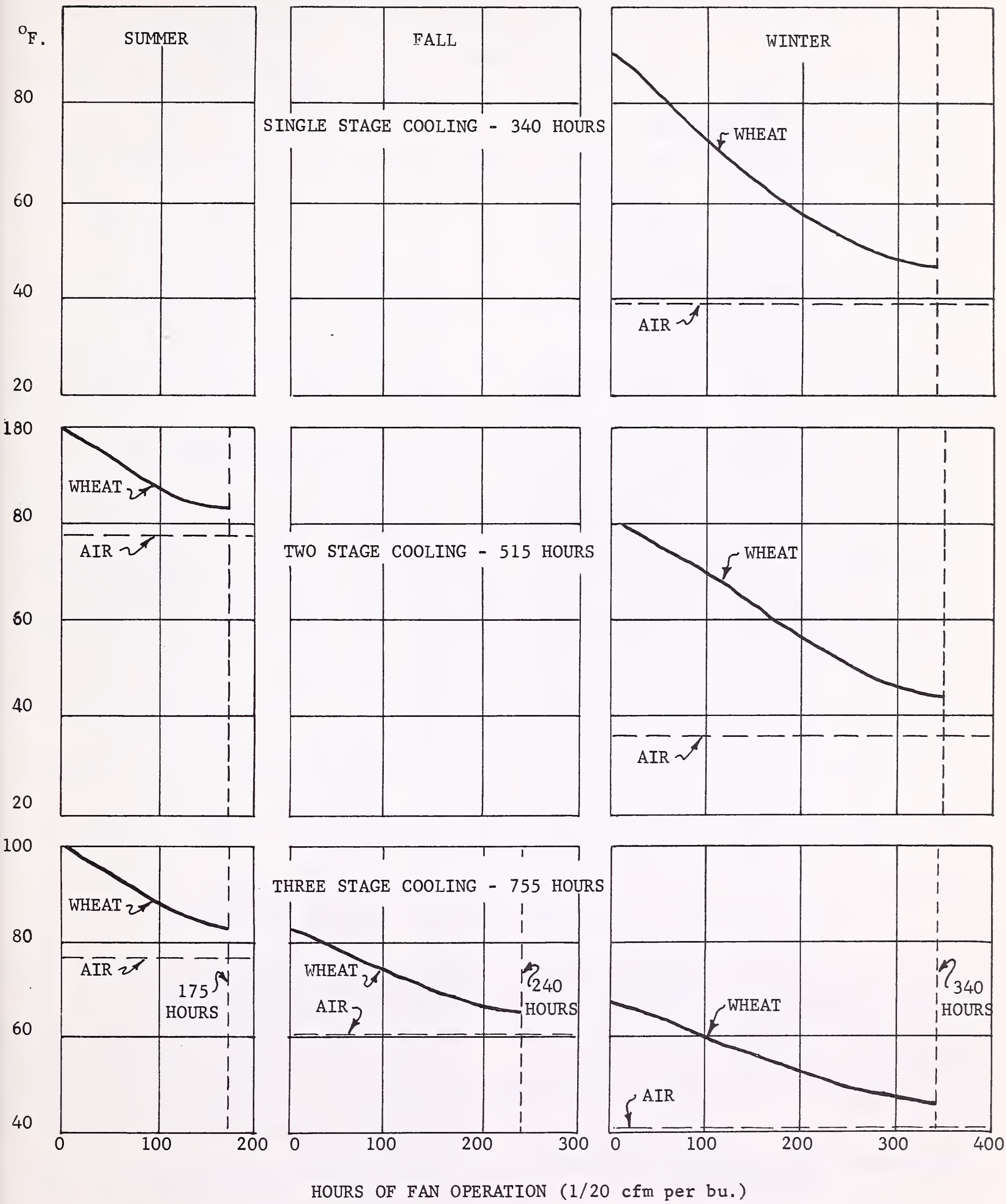
High-limit temperatures.—In general, a high-limit air temperature that is at least 10° F. below the average grain temperature is necessary to accomplish appreciable cooling during a stage. Suitable high-limit air temperatures by seasons are: summer, 85° F.; fall, 70° F.; and winter, 50° F. Fans are operated only when the air temperature is at, or below, these limits and when the relative humidity of the air is satisfactory. These temperatures were selected on the basis of an analysis of past weather records and results of grain aeration tests. In the tests, grain was cooled to temperatures equal to or slightly lower than the high-limit air temperature by the time a cooling zone had been moved completely through a bin of grain.

Low-limit temperatures.—In summer and fall aeration, no low-limit air temperature is needed. For winter aeration, a low limit is desirable to prevent the development of layers of cold grain (below freezing) during extended periods of cold weather.

A low limit reduces the hours available for fan operation during the winter. One of the common difficulties in the operation of aeration systems at commercial elevators has been the use of low-limit temperature that is too high; for example, only 10° F. below the high limit. With a combination of a low airflow rate and a restrictive low-limit temperature, it is difficult to complete cooling in the time available. It is important to move a cooling zone completely through the grain in storage during the winter.

TEMPERATURE OF WHEAT DURING AERATION

In Upright Storages in Kansas



AVERAGE 1955-59

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FIGURE 3

WEATHER IN WICHITA, KANSAS, 4 TYPICAL DAYS

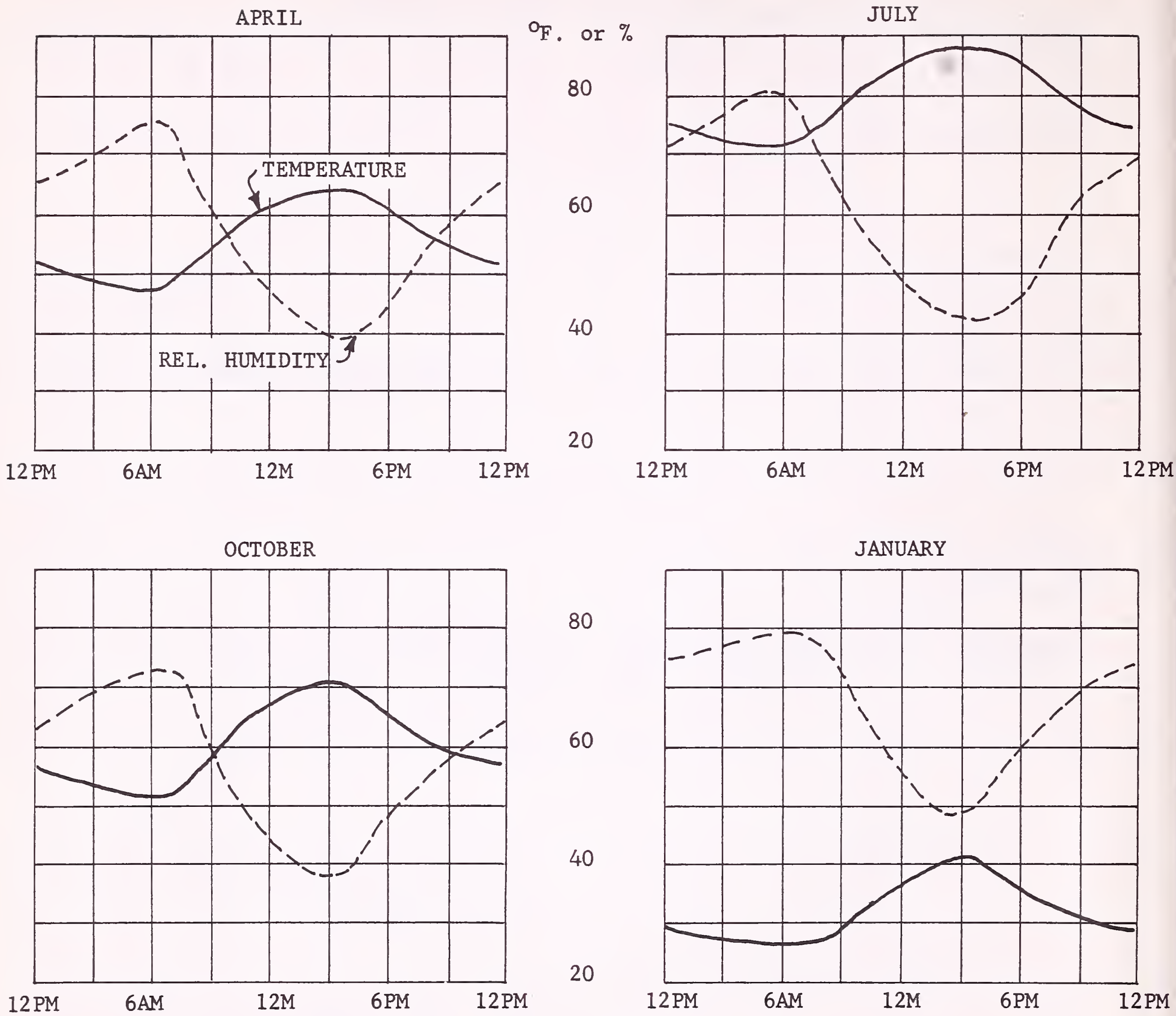

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Figure 4

In general, low-limit temperatures are suitable for winter operation only with airflow rates of 1/40 cfm per bushel and higher. With airflow rates between 1/40 and 1/20 cfm per bushel, a low limit of 20° F. can be used without unduly limiting fan operation. With airflow rates of 1/20 cfm per bushel or more, a low limit of 30° F. can be used.

DESIRABLE RELATIVE HUMIDITY OF INTAKE AIR

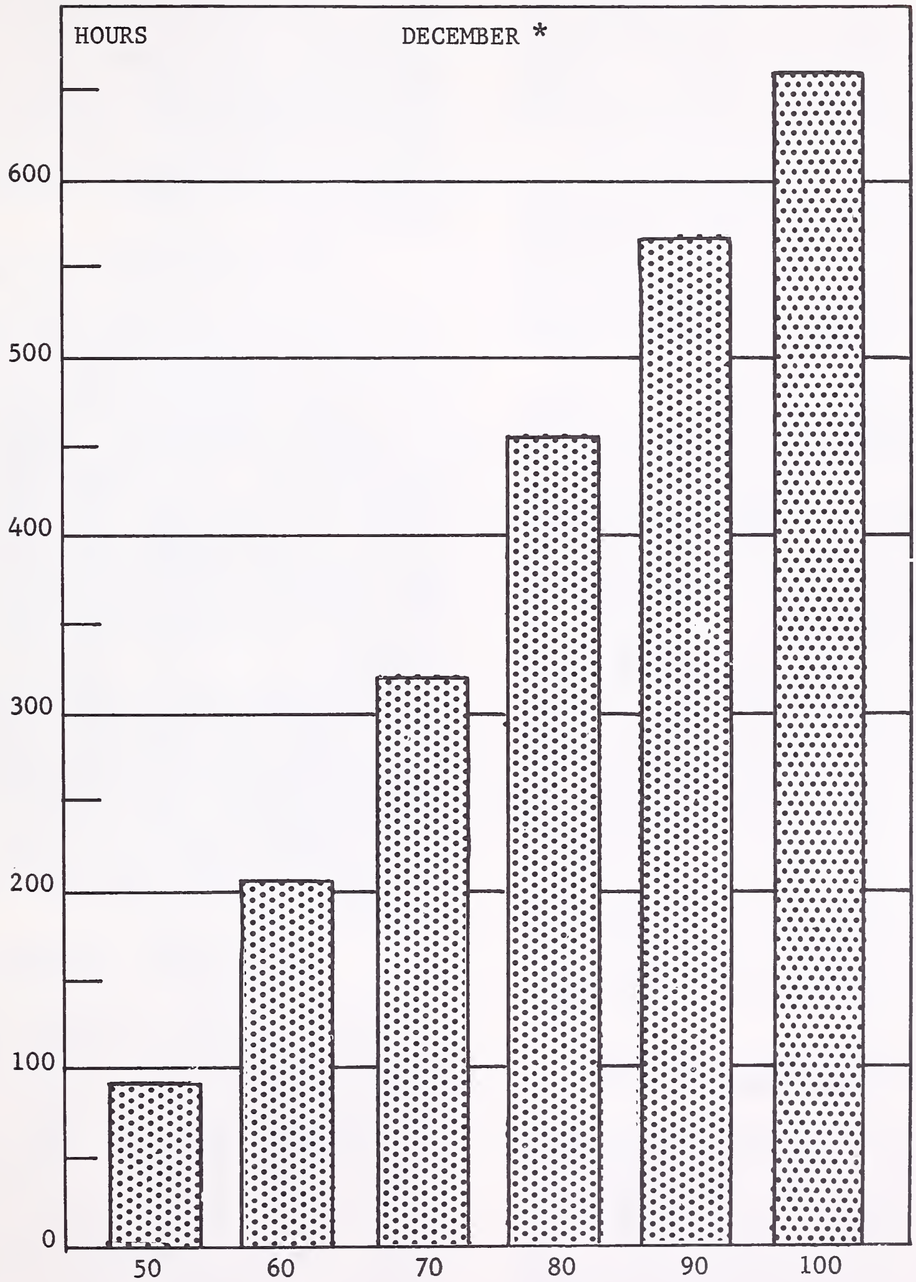
In summer and fall, fans may be operated at all times when relative humidity is 90 percent or below (and air temperatures are satisfactory). This high limit eliminates fan operation during extended periods of rain and fog.

Winter operation is satisfactory with a high-limit relative humidity of 80 percent to restrict increase in grain moisture at the point where air enters the grain. This limit allows fans to operate long enough to accomplish the desired cooling and maintains a moisture content below 13 percent in the surface grain.

Cooling may be incomplete when an overly restrictive relative humidity limit prevents sufficient fan operation. Limits of less than 80 percent have been used at some commercial grain elevators. Figure 5 shows the hours available for fan opera-

HOURS AVAILABLE TO AERATE STORED GRAIN

At Different High Limits of Relative Humidity and When Air Temperature is Below 50° F.



* 10-Year Average, 1950-59, Wichita, Kans.

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FIGURE 5

tion at one location with relative humidity limits ranging from 50 to 100 percent for winter operation. It is desirable to use the highest limit that will maintain a safe moisture level in stored grain.

Relative humidity of the aeration air is not critical for the bulk of the grain when the air temperature is 10 degrees or more below the grain temperature. At the cooling front in the stored grain, the air is warmed as the grain is cooled. Thus, the relative humidity of this air is lowered and there is no reason for the grain moisture to increase above the safe storage level.

However, the relative humidity of the air is important in controlling the moisture content of the grain near the point where the air is introduced. The grain at this point is the first to cool and when cooled tends to come to equilibrium with the incoming air. As a result some increase in grain moisture has been observed in the surface few feet of grain during winter operation.

Continuous aeration with intake air at a relative humidity of 90 percent in the summer and fall and 80 percent in the winter could increase the moisture content of grain considerably above the safe storage level. However, the daily average relative humidity of the intake air will be much lower than 80 or 90 percent and the moisture of the grain near the surface will tend to come to equilibrium with this average relative humidity.

In aeration tests using 80 percent and 90 percent limits, the moisture of the grain near the surface was maintained at a safe storage level. Figure 6 illustrates the moisture changes found in grain near the surface in a representative bin of wheat during aeration in the summer, fall, and winter, and during the following storage period. Some increase in moisture content was found in the top 5 feet of grain in upright bins during winter aeration but the moisture did not exceed safe storage limits. Much of this moisture in the surface layers is dissipated during the following spring and summer without aeration, apparently due to normal air circulation over and through the surface grain.

HOURS AVAILABLE FOR FAN OPERATION

Recorded weather data can be used to predict the number of hours during which air temperature and humidity will be within selected limits. The information is valuable in establishing limits that will permit fans to operate long enough to cool the grain. No matter how beneficial it is to use cool, dry air, the benefit is lost if the fans are stopped before aeration is complete.

Hourly readings of temperature and relative humidity have been recorded and published by the U.S. Weather Bureau since late 1949 for the following locations in the Hard Winter Wheat area: Kansas City, Topeka, Wichita, Oklahoma City, Amarillo, Denver, and Omaha. The readings provide a basis for predicting cooling results with aeration systems used at each of the locations.

Table 6 (appendix) shows a summary prepared from weather data for Wichita. The average hours available for fan operation at various temperature and relative humidity limits are given for each month during the 10-year period of record, 1950–59. The table also shows the maximum and minimum hours available by months.

Summaries were prepared for Kansas City, Oklahoma City, Amarillo, Denver, and Omaha, as well as for Wichita (table 7, appendix). Identical temperature and relative humidity limits were analyzed for each location. The summaries were the basis for the fan operation schedules given in tables 4 and 5.

TIME REQUIRED TO COOL

The basic time required to cool grain under typical conditions in the Hard Winter Wheat area is shorter in the summer than in the fall, and shorter in the fall than in the winter (table 1).[2] This variation is attributed to seasonal differences in the amount of evaporative cooling that occurs during aeration. For example, in three-stage aeration tests when grain was cooled approximately 15° F. per stage, grain moisture was reduced as follows: Summer stage, $\frac{1}{3}$ percent; fall stage, $\frac{2}{10}$ percent; and winter stage, $\frac{1}{10}$ percent. The amount of moisture removed from the grain is small, but the resulting evaporative cooling is appreciable.

In the aeration tests, the calendar time required for cooling grain in an upright storage at an airflow rate of $\frac{1}{20}$ cfm per bushel averaged about 2 weeks in the summer, 3 weeks in the fall, and 4 weeks in the winter. Although the time in hours was approximately the same each year, the calendar time differed from year to year because of variations in weather. Fans were automatically controlled during the tests.

AUTOMATIC CONTROL

Automatic controls can prevent operation of fans during times when no cooling can be accomplished, when grain moisture might increase, when the noise from the fan may be objectionable, and when electrical demand is at a peak.

An automatic control for operating aeration systems is shown in figure 7. Aeration controls usually include high-limit and low-limit temperature switches, a high-limit humidity switch, and a relay. Additional accessories may include a timeclock, a time-delay starter, an elapsed-time recorder, and a selector switch for manual or automatic operation. A magnetic motor starter is usually required for fan motors when automatic controls are used. Small motors can be started or stopped directly by temperature and humidity switches. A manual disconnect switch and motor

[2] Basic time is the time required to move a cooling zone through a bin of grain at a given airflow rate when no allowance is made for nonuniformity of airflow.

MOISTURE IN WHEAT DURING STORAGE

Changes Caused by Aeration

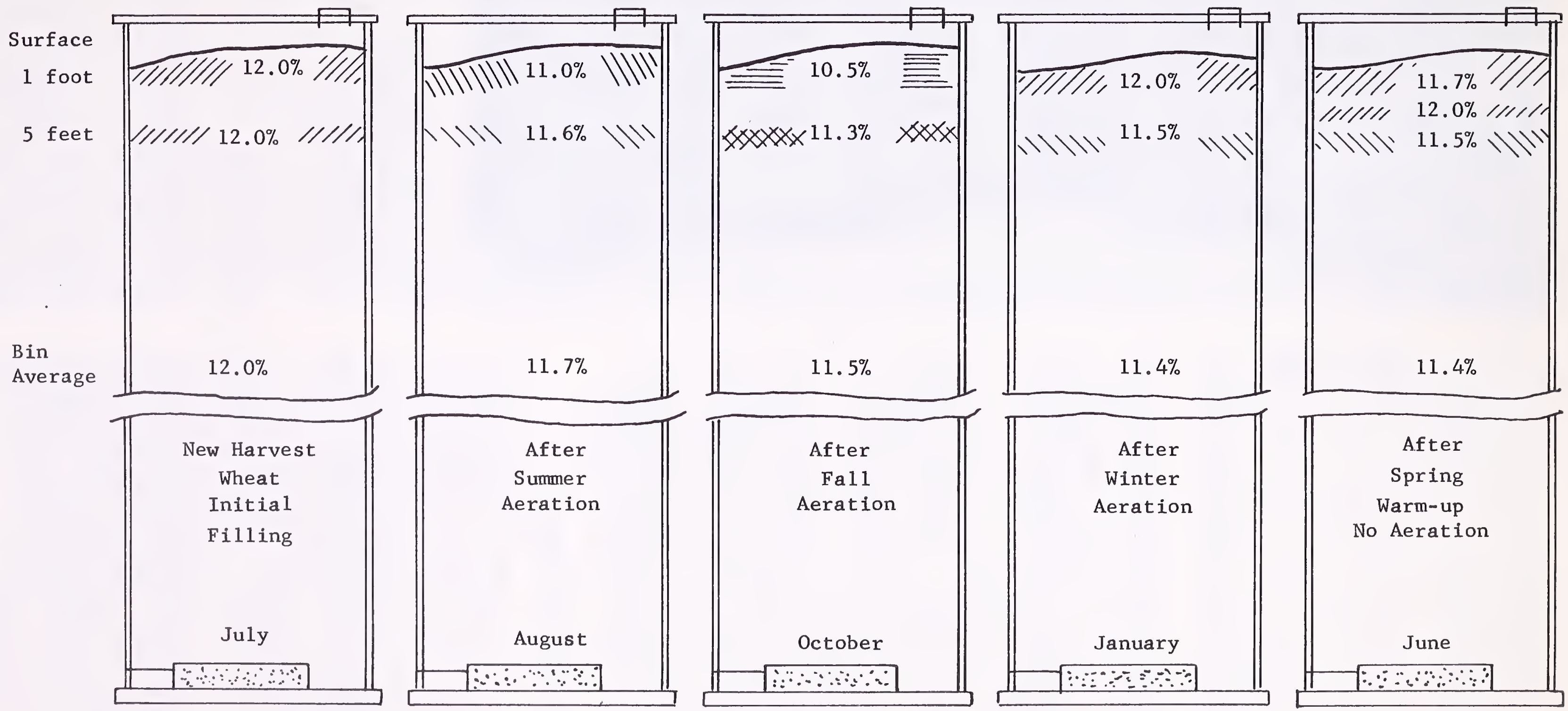

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FIGURE 6

TABLE 1.—*Basic time required to cool grain in the Hard Winter Wheat area*[1]

Airflow rate and seasonal stages	Basic time
	Hours
1/20 cfm per bushel:	
Summer	160
Fall	220
Winter	310
1/40 cfm per bushel:	
Summer	320
Fall	440
Winter	620

[1] Based on tests with wheat and grain sorghum cooled approximately 15° F. during each season.

protection should be incorporated between the power supply and the motor.

The high-limit and low-limit temperature switches and the high-limit humidity switch are wired in series. Then selected conditions of both temperature and relative humidity must be satisfied before the fan will operate.

Controls should be placed to sense outside air approximating that entering the grain. They should be protected from the weather but exposed to freely moving air. A shady location is preferred but a louvered housing painted white may be used for sunny locations.

Automatic controls require calibration and frequent checking to insure accuracy. Current local weather bureau readings of temperature and relative humidity can be utilized. Also psychrometers are useful in calibrating controls for both temperature and relative humidity. Timeclocks must be reset each time electrical service is interrupted. Controls should be cleaned frequently, particularly the hair elements of humidity switches.

COST OF OPERATION

Operating costs for an aeration system consist of power, maintenance, repairs, and labor. The major operating cost is for electric power, which varies with the kind and depth of grain, airflow rate, operation schedule, and hours of fan operation. Table 2 shows typical electric power costs for aerating wheat in upright storages in the Hard Winter Wheat area. Table 3 shows typical costs for flat storages.

Operating costs are highest in winter because the time required for cooling is longer in winter than in summer and fall. For example, in an upright storage with wheat aerated at $\frac{1}{30}$ cfm per bushel, the electric power costs are: Summer stage, 0.07 cent per bushel; fall stage, 0.095 cent per bushel; winter stage, 0.135 cent per bushel. The total cost is $\frac{3}{10}$ cent per bushel for three stages. When fewer than three stages are needed, the total costs for electric power are: single stage (winter), 0.135 cent per bushel; two stages (summer and winter), 0.205 cent per bushel.

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FIGURE 7.—*Automatic control for aeration systems. Includes high-limit temperature control, low-limit temperature control, hair-element humidistat, timeclock, control switch (position for manual, automatic, and off, with indicator lights), and a relay.*

The cost of operating aeration systems also varies with the airflow rate. In three-stage aeration in upright storages, the electric power cost at different airflow rates was: $\frac{1}{20}$ cfm per bushel, 0.425 cent per bushel; $\frac{1}{30}$ cfm per bushel, 0.30 cent per bushel; and $\frac{1}{40}$ cfm per bushel, 0.255 cent per bushel.

The resistance to airflow of most grain increases almost directly in proportion to the grain depth. Power costs, therefore, are lower for aerating grain in flat storages than in upright storages. For three-stage cooling in a flat storage at 1/15

TABLE 2.—*Electric power costs and fan operation time for aeration of wheat stored 100 feet deep in an upright storage*

Airflow rate and seasonal stage	Fan operation time to cool [1]	Electric power cost per bushel [2]
1/20 cfm per bushel:	*Hours*	*Cents*
Summer	175	0. 10
Fall	240	. 135
Winter	340	. 19
Total	755	. 425
1/30 cfm per bushel:		
Summer	265	. 07
Fall	360	. 095
Winter	510	. 135
Total	1, 135	. 30
1/40 cfm per bushel:		
Summer	350	. 06
Fall	480	. 08
Winter	680	. 115
Total	1, 510	. 255

[1] Basic time required to cool was increased by 10 percent to allow for nonuniform air distribution.
[2] Based on power costs of 4 cents per kilowatt-hour.

cfm per bushel the electric power cost was 0.155 cent per bushel (table 3) and for aerating an upright storage at 1/30 cfm per bushel the cost was 0.30 cent per bushel (table 2). Because the airflow is not as uniform in a flat storage, an airflow rate of 1/15 cfm per bushel requires about the same fan operation time to complete cooling as 1/30 cfm per bushel in an upright storage.

Labor requirements for operating aeration systems are relatively small. The jobs include (1) starting and stopping fans, (2) adjusting slide gates or dampers, (3) opening ventilators or windows, (4) calibrating and setting automatic controls, (5) maintaining records of fan operation, exhaust air temperatures, and grain temperatures, and (6) inspecting systems daily. The jobs require an average of only a few minutes a day. In an 8-bin manifold system for wheat in an upright storage with a capacity of 165,000 bushels, the labor required for each stage was 2.4 man-hours for summer, 2.8 man-hours for fall, and 5.9 man-hours for winter. Half of the bins were aerated during the summer and fall, and all bins during the winter stage. The labor requirement was an average of 5 man-minutes per day during the time the fans were operating. The labor cost was approximately 0.01 cent per bushel.

The cost of maintenance and repairs for aeration equipment is not well established. Representative annual maintenance and repair costs have been estimated at one-half of 1 percent of the replacement cost. With a replacement cost of $3,200 for the 8-bin system, the annual maintenance and repair cost would be $16.00, or 0.01 cent per bushel.

TABLE 3.—*Electric power costs and fan operation time for an aeration system in a flat storage filled with wheat* [1]

Airflow rate and seasonal stage	Fan operation time to cool [2]	Electric power cost per bushel [3]
1/10 cfm per bushel:	*Hours*	*Cents*
Summer	160	0. 045
Fall	220	. 06
Winter	310	. 085
Total	690	. 19
1/15 cfm per bushel:		
Summer	240	. 035
Fall	330	. 05
Winter	465	. 07
Total	1, 035	. 155
1/20 cfm per bushel:		
Summer	320	. 03
Fall	440	. 045
Winter	620	. 06
Total	1, 380	. 135
1/30 cfm per bushel:		
Summer	480	. 025
Fall	660	. 04
Winter	930	. 055
Total	2, 070	. 12

[1] The building is 100 feet wide, with grain 34 feet deep at the peak and 20 feet deep at the side walls.
[2] Basic time required to cool has been doubled to allow for nonuniform air distribution.
[3] Based on power costs of 4 cents per kilowatt-hour.

AERATION SCHEDULES

Recommended fan operation schedules for aeration in the Hard Winter Wheat area are shown for upright storages in table 4, and for flat storages in table 5. These schedules are for different types of aeration systems and for representative airflow rates. The schedules and the temperature and relative humidity limits given will permit effective use of aeration systems to prevent mold, minimize insect activity, prevent moisture migration, and establish desirable storage conditions.

The schedules allow time to complete a cooling stage during each season of the year whenever possible. They were chosen by combining information about (1) desired intake air conditions, (2) time available for fan operation, and (3) the time required to cool, as discussed in the previous section.

TABLE 4.—*Upright storages in the Hard Winter Wheat area: Fan operation schedules for aeration of new harvest wheat with 11 to 13 percent moisture*

Aeration system, airflow rate, and season [1]	Time required to cool [2]	Months when fan is operated	Control limits: Temperature: High limit	Control limits: Temperature: Low limit	Control limits: Relative humidity (high limit)	Remarks
Manifold or fixed fan system:						
1/20 cfm per bushel (all bins):	*Hours*		*°F.*	*°F.*	*Percent*	
Summer	175	July–Aug.	85	--------	90	
Fall	240	Sept.–Oct.	70	--------	90	
Winter	340	Nov.–Dec.	50	30	80	
		Or				
		Dec.–Jan.	50	30	80	Omaha: include Feb.
		Or				
		Nov.–Dec.	50	--------	80	
1/30 cfm per bushel (all bins):						
Summer	265	July–Aug.	85	--------	90	
Fall	360	Sept.–Oct.	70	--------	90	
Winter	510	Nov.–Dec.–Jan.	50	30	80	Omaha: include Feb.
		Or				
		Dec.–Jan.	50	20	80	
		Or				
		Nov.–Dec.	50	--------	80	Okla. City: include Jan.
1/40 cfm per bushel (all bins):						
Summer	350	July-Aug.	85	--------	90	
Fall	480	Sept.-Oct.	70	--------	90	
Winter	680	Nov.-Dec.-Jan.	50	30	80	Okla. City and Omaha: use 25° F. low limit.
		Or				
		Dec.-Jan.-Feb.	50	20	80	Omaha: include Nov.
		Or				
		Nov.-Dec.-Jan.	50	--------	80	
Manifold system:						
1/20 cfm per bushel (half of bins at one time):						
Summer (all bins)[3]	350	July-Aug.	85	--------	90	
Fall (all bins)[3]	480	Sept.-Oct.	70	--------	90	
Winter:						
Early (half of bins)	340	Nov.-Dec.	50	20	80	
Late (half of bins)	340	Jan.-Feb.	50	20	80	
Alternate (all bins at one time)[4]	510	Dec.-Jan.	50	20	80	Omaha: include Feb.
1/30 cfm per bushel (half of bins at one time):						
Summer (all bins)[3]	530	July-Aug.	85	--------	80	
1/30 cfm per bushel (half of bins) (cont.):						
Fall (all bins) [3]	360	Sept.–Oct.	70	--------	90	
Winter:						
Early (half of bins)	510	Nov.–Dec.	50	--------	80	
Late (half of bins)	510	Jan.–Feb.	50	--------	80	
Alternate (all bins at one time) [5]	680	Dec.–Jan.–Feb.	50	30	80	Omaha: include Nov.
1/40 cfm per bushel (half of bins at one time):						
Summer (all bins) [3]	700	July–Aug.	85	--------	90	Okla. City and Wichita: include June.
Fall (all bins) [3]	480	Sept.–Oct.	70	--------	90	
Winter:						
Early (half of bins)	680	Nov.–Dec.	50	--------	80	Okla. City and Omaha: use alt. winter schedule of 55° F. high limit.
Late (half of bins)	680	Jan.–Feb.	50	--------	80	
Alternate (all bins at one time) [6]	1, 020	Dec.–Jan.–Feb.	50	--------	80	

See footnotes at end of table.

TABLE 4.—*Upright storages in the Hard Winter Wheat area: Fan operation schedules for aeration of new harvest wheat with 11 to 13 percent moisture*—Continued

Aeration system, airflow rate, and season [1]	Time required to cool [2]	Months when fan is operated	Control limits: Temperature High limit	Control limits: Temperature Low limit	Control limits: Relative humidity (high limit)	Remarks
	Hours		*°F.*	*°F.*	*Percent*	
Portable fan system:						
1/20 cfm per bushel (half of bins at one time):						
Summer (all bins) [3]	350	July–Aug	85		90	
Fall (all bins) [3]	480	Sept.–Oct	70		90	
Winter:						
Early (half of bins)	340	Nov.–Dec	50	20	80	
Late (half of bins)	340	Jan.–Feb	50	20	80	
1/30 cfm per bushel (half of bins at one time):						
Summer (all bins) [3]	530	July–Aug	85		90	
Fall (all bins) [3]	360	Sept.–Oct	70		90	
Winter:						
Early (half of bins)	510	Nov.–Dec	50		80	
Late (half of bins)	510	Jan.–Feb	50		80	
Portable fan system:						
1/20 cfm per bushel (one-fourth of bins at one time):						
Summer (all bins) [7]	700	July–Aug	85		90	Okla. City and Wichita: include June.
Fall (half of bins) [8]	480	Sept.–Oct	70		90	
Winter (all bins) [7]	1,360	Nov. through Feb.	50		80	Okla. City and Omaha: use 55° F. high limit.

[1] For new harvest wheat with 11 percent moisture or less, fall aeration may be eliminated. Old wheat may need only winter aeration.
[2] Basic time required to cool (table 1) increased by 10 percent to allow for nonuniform airflow.
[3] All bins aerated, one-half at a time, during two consecutive periods of fan operation.
[4] When aerating all bins at one time airflow approximately 1/30 cfm/bu. Note: Check with supplier of system as some fans may be overloaded if more than half of bins are aerated at one time and some systems may supply less than 1/30 cfm/bu. when aerating all bins at one time.
[5] When aerating all bins at one time airflow approximately 1/40 cfm/bu. See Note, footnote 4.
[6] When aerating all bins at one time airflow approximately 1/60 cfm/bu. See Note, footnote 4.
[7] All bins aerated, one-fourth at one time, during four consecutive periods of fan operation.
[8] Half of bins aerated, one-fourth at one time, during two consecutive periods of fan operation.

It is desirable to verify the airflow rate of each aeration system by actual tests following installation. Airflow is not uniform in most aeration systems. Part of the grain may be aerated above the average airflow rate and another part below the average. The grain in an area of low airflow will be the last to cool. On the basis of test results and industry experience, the basic time required to cool was increased by 10 percent for upright storages to allow for nonuniform airflow. The basic time for flat storages was doubled.

UPRIGHT STORAGE

Cooling schedules.—The cooling schedules for upright storages (table 4) were developed for new harvest wheat. A three-stage cooling is scheduled, with a complete stage in summer, fall, and winter.

Grain moisture may be a basis for modifying the aeration schedule. Three-stage cooling is desirable when moisture in wheat is near the maximum safe storage limit of 13 percent. Two-stage cooling, with no fall operation, generally is satisfactory for bins with 11 percent moisture or less. Two-stage cooling costs less and results in less change in grain moisture.

For old wheat, carried over in storage from the previous year, a winter aeration usually will be satisfactory. Also, wheat delivered to commercial storage from farm storage during the winter can be mixed and cooled using a winter aeration schedule. The temperature and relative humidity limits are the same as for new grain.

The recommended schedules have enough flexibility to permit short-term operation between stages and after planned aeration is complete. Nonscheduled uses of aeration may include grain fumigation, emergency cooling, removal of odors, holding wet grain for brief periods, or aerating

Table 5.—*Flat storages in the Hard Winter wheat area: Fan operation schedules for aeration of new harvest wheat with 11 to 13 percent moisture*

Aeration system, airflow rate, and season [1]	Time required to cool [2]	Months when fan is operated	Control limits: Temperature: High limit	Control limits: Temperature: Low limit	Control limits: Relative humidity (high limit)	Remarks
	Hours		°*F.*	°*F.*	*Percent*	
Fixed fan system:						
1/10 cfm per bushel (entire storage):						
Summer	160	July–Aug	85		90	
Fall	220	Sept.–Oct	70		90	
Winter:						
Early	310	Nov.–Dec	50		80	
Late	310	Jan.–Feb	50	30	80	Okla. City: use 25° F. low limit; Omaha: use 20° F., low limit.
Alternate:						
Early	310	Nov.–Dec	50	30	80	
Late	310	Dec.–Jan	50	30	80	Omaha: include Feb.
1/20 cfm per bushel (entire storage):						
Summer	320	July–Aug	85		90	
Fall	440	Sept.–Oct	70		90	
Winter	620	Nov.–Dec.–Jan	50	30	80	Omaha: use 25° F. low limit.
		or				
		Nov.–Dec	50		80	Okla. City: include Jan.
1/30 cfm per bushel (entire storage):						
Summer	480	July–Aug	85		90	
Fall	660	Sept.–Oct	70		90	Wichita and Okla. City: use 75° F. high limit.
Winter	930	Nov.–Dec.–Jan	50	20	80	Okla. City & Omaha: include Feb.
		or				
		Nov.–Dec.–Jan	50		80	Okla. City: include Feb.
Portable fan system:						
1/10 cfm per bushel (half of storage at one time):						
Summer (entire storage) [3]	320	July–Aug	85		90	
Fall (entire storage) [3]	440	Sept.–Oct	70		90	
Winter (entire storage) [3]	620	Nov.–Dec.–Jan	50	30	80	Omaha: use 25° F. low limit.
		or				
		Nov.–Dec	50		80	Okla City: include Jan.
1/20 cfm per bushel (half of storage at one time):						
Summer (entire storage) [3]	640	July–Aug	85		90	
Fall (half of storage)	440	Sept.–Oct	70		90	
Winter (entire storage) [3]	1, 240	Nov. through Feb	50		80	Okla. City: use 55°F. high limit.
1/10 cfm per bushel (one-fourth of storage at one time):						
Summer (entire storage) [4]	640	July–Aug	85		90	
Fall (half of storage) [5]	440	Sept.–Oct	70		90	
Winter (entire storage) [4]	1, 240	Nov. through Feb	50		80	Okla. City: use 55°F. high limit.

[1] Old wheat may need only fall and winter aeration or winter aeration.
[2] Basic time required to cool (table 1) doubled to allow for nonuniform airflow.
[3] Entire storage aerated, one-half at one time, during two consecutive periods of fan operation.
[4] Entire storage aerated, one-fourth at one time, during four consecutive periods of fan operation.
[5] One-half of storage aerated, one-fourth at one time, during two consecutive periods of fan operation.

grain received from farm storage in late winter and early spring. The recommended operation schedules are based on having grain cooled by the end of February. If necessary considerable cooling also can be accomplished in March and April. High limit temperatures of 50° F. in March and 60° F. in April are suitable for most of the Hard Winter Wheat area.[3] No low limit temperature need be used. A high-limit relative humidity of 80 percent is suitable for both months.

Airflow rate.—The airflow rates shown in table 4 are suitable for aeration in upright storages. With portable fan systems and certain manifold systems, only a part of the grain can be aerated at one time. Fan operation times for these systems in the table are long enough to cool all the grain in the storage. For example, a portable fan system providing 1/20 cfm per bushel for the grain in half of the bins is given as much time to cool all the grain in the storage as a system with a fixed fan for each bin at 1/40 cfm per bushel.

FLAT STORAGE

Cooling schedules.—The cooling schedules for flat storages (table 5) were developed for new harvest wheat. Cooling is provided during the summer, fall, and winter.

For old wheat, in its second or third year in storage, fall and winter aeration can be used. Summer aeration is seldom of value. Temperature and relative humidity limits for fall and winter aeration of old grain are the same as for new grain. Winter aeration only will probably be sufficient when old grain is in good condition and located where moisture migration is not a serious problem.

Airflow rate.—Grain in flat storages can be aerated at the airflow rates shown in table 5. Fan operation time given for portable fan systems, which can aerate only a portion of the storage at one time, are sufficient to cool the entire storage. For example, a portable fan system aerating half of the storage at 1/10 cfm per bushel takes as long to cool all the grain as a system with fixed fans for the entire storage at 1/20 cfm per bushel.

GRAINS OTHER THAN WHEAT

The main discussion and the recommended operating schedules are based on wheat. Other grains stored in the Hard Winter Wheat area include sorghum grain, corn, oats, barley, and soybeans. The operating schedules in table 4 and table 5 can be adapted for aerating these grains.

Grain sorghum is harvested in the fall in the Hard Winter Wheat area. A winter aeration stage usually will suffice for grain sorghum placed in storage at a safe moisture level. In some cases, both fall and winter aeration may be desired. The temperature and relative humidity limits shown in tables 4 and 5 are suitable for aeration of grain sorghum.

New corn is delivered to commercial storage from early fall until winter in different parts of the area. Also, old corn from the previous year may be delivered from farm storage during late summer and early fall. Shelled corn is particularly subject to moisture migration; aeration should be started as soon as possible after the corn goes into storage. Fall and winter stages are frequently used. In addition, a small amount of fan operation each day between the fall and winter stages and after the winter stage (for the remainder of the winter season) may be desirable. The temperature limits recommended for fall and winter aeration of wheat also are suitable for shelled corn and soybeans stored at a safe moisture content. High-limit relative humidities of 80 percent in the fall and 70 percent in the winter are desirable for aerating shelled corn and soybeans.

Oats and barley may be aerated in the same way as wheat.

AERATING FOR SPECIAL PURPOSES

Aeration systems are sometimes used for (1) storing grain with a moisture content slightly above safe storage level, (2) holding wet grain for brief periods, (3) emergency cooling, (4) removing odors, and (5) applying fumigants. These purposes usually require shorter periods of fan operation than the schedules in table 5.

Some of the problems that arise in operating aeration systems for special uses have been explored in research tests. Results of these tests are used as a basis for suggestions presented in this section.

[3] For Oklahoma City and southern Oklahoma, high-limit temperatures of 60° F. in March and 70° F. in April are suitable.

STORING GRAIN WITH MOISTURE SLIGHTLY ABOVE SAFE STORAGE LEVEL

Storing grain with moisture content slightly above the safe storage level should not be a regular practice. However, in some harvest situations, the additional risk may be justified. Aeration can aid in maintaining quality of the damp grain.

For this discussion, grain with 13 to 15 percent moisture—about 2 percent above safe storage level—is considered for storage periods of less than 1 year. This grain must be segregated from other grain and stored in separate small bins. Even with aeration, damp grain must be completely mixed or blended to a uniform moisture

content. Frequent inspection is necessary and every precaution should be taken to avoid spoilage.

Eight aeration tests were conducted with wheat and grain sorghum with 13 to 15 percent moisture. The two following examples are typical of the eight tests.

One bin of wheat with initial average moisture of 14 percent was aerated in three stages, starting when the bin was filled on July 8. The airflow rate was 1/20 cfm per bushel. The average grain temperature was reduced from 83° to 78° F. in July, from 78° to 57° F. in September and October, and from 57° to 44° F. in November and December. The total fan operation time was 1,028 hours, including a normal summer stage, a fall stage extended to about double the normal fan operating time, and a normal winter stage. At the end of the test in late January, the final average moisture content was 13.1 percent. The official grade changed from No. 1 Hard Winter Tough, at the start of the test, to No. 1 Hard Winter at the end of the test. There was no change in other grain quality factors, including germination, fat acidity, and mill and bake tests.

Another bin was filled with grain sorghum at an average moisture content of 14.6 percent on November 8. At the end of storage on the following June 22, the final moisture content was 13.6 percent. The fan was operated 515 hours at an airflow rate of 1/20 cfm per bushel, during 6 weeks after filling the bin. The grain was cooled from 58° to 43° F. After the 7½-month storage period, the grain had an excellent appearance and "fresh grain" odor. Official grade and germination tests also indicated that grain quality had been maintained.

New harvest wheat with moisture slightly above the safe storage level would probably need three-stage cooling—summer, fall, and winter. The calendar schedule and the temperature and relative humidity limits would be those presented in table 4. In addition, fans should be operated a short time several days each week between the summer and fall stages, and the fall and winter stages. This can be provided by use of automatic temperature and relative humidity controls combined with timeclock control. Temperature and relative humidity limits would be the same as during the previous stage. Timeclock settings allowing operation between 8 a.m. and 11 a.m. each day have been satisfactory in the Hard Winter Wheat area. Fan operation averaged about 2 hours daily during tests with these control settings. Similar results can be obtained by manual operation for 10 to 15 hours weekly.

For new grain sorghum harvested in early fall, with moisture slightly above the safe storage level, two-stage cooling in the fall and winter is suggested. For late fall harvest, a single-stage cooling in the winter would be sufficient. Temperature and relative humidity limits are those presented in table 5.

HOLDING WET GRAIN FOR BRIEF PERIODS

Sometimes it is necessary to hold wet grain in storage for brief periods until it can be moved to a dryer or blended with dry grain for storage or marketing. Aeration of wet grain is helpful in (1) lowering grain temperature and thus reducing the rate of mold growth, (2) removing heat generated by mold growth, preventing the development of hot spots, (3) redistributing moisture from small pockets of very wet grain, and (4) removing a small amount of moisture from the grain mass. Airflow rates used for aeration are not sufficient to perform a major drying operation.

For this discussion grain with moistures of 15 to 18 percent, considerably above safe storage level, is considered. One test bin of grain sorghum with an average moisture content of 16 percent was partially filled on October 28 and held for 16 days. The grain was aerated for 229 hours at an airflow rate of approximately 1/3 cfm per bushel. The final average moisture content was 15.2 percent and there was no loss in grain quality.

As a general guide, summer-harvested grain with temperatures much above 70° F. may not be held more than 1 week. Fall- and winter-harvested grain with temperatures below 70° F. may be held for 1 month and perhaps longer under favorable circumstances. Exceeding these limits may result in mold growth, objectionable odors, and loss in market quality.

Usually wet grain is held in small quantities and is not put in large flat storages. Under some situations grain with 13 to 15 percent moisture may also be treated as wet grain and held for short periods before drying or blending.

Continuous operation of fans is usually necessary for holding wet grain. For summer-harvested grain with more than 15 percent moisture, there is little advantage in limiting either temperature or relative humidity. Fans are operated continuously until the grain can be moved to a dryer or blended. For holding wet grain harvested in the fall and winter, fans are operated continuously to move a cooling zone through the grain as rapidly as possible. Then temperature and relative humidity controls may be used to provide intermittent operation during the remainder of the holding period. During the latter period a low-limit temperature setting of 30° F. combined with a high-limit relative humidity setting of 80 percent has been satisfactory in the Hard Winter Wheat area. These limits should provide about 12 hours of fan operation each day and a limited amount of drying in the surface layers of grain.[4]

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[4] Wichita, Kans., weather data, 1950–59.

EMERGENCY COOLING

Aeration systems can be used to rapidly cool grain in immediate danger of going out of condition. Grain in storage or new receipts of grain may heat due to mold, insects, or other deterioration. This excess heat generally can be removed by aeration. Fans should be operated continuously under such emergency circumstances to accomplish cooling as rapidly as possible. When cooling grain in bins that are partially full, the instructions furnished with the aeration system must be observed to avoid overloading the fan motor.

Aeration is also used to remove "hot spots" without turning the grain. Small pockets of grain within a bin may heat due to insects and mold. One test bin of wheat 102 feet deep had an average grain temperature of 43° F. in early March. A hot spot attributed to insects had developed during February, with the grain temperature increasing to 75° F. at one location 24 to 28 feet above the bin floor. No increase was measured in other parts of the bin. Aeration was started with automatic controls set to operate the fan when the outside air temperature was below 48° F. and the relative humidity less than 80 percent. With an airflow rate of $\frac{1}{50}$ cfm per bushel, the hot spot was moved downward and out of the grain during 300 hours of fan operation. Hot spots can be removed by continuous operation or by intermittent operation under automatic control.

REMOVING ODORS

Grain stored under optimum conditions retains its fresh odor; this has been particularly noted in aerated grain. Grain stored under less satisfactory conditions may develop storage odors—musty, moldy, sour, and fermenting. Also, some insects impart strong objectionable odors to stored grain. Other foreign odors may be imparted to the grain during handling from the harvest field to the final market.

Aeration will remove or reduce some of the objectionable odors. Other more persistent odors may be changed little or not at all. The requirements and limitations of odor removal have not been determined completely.

Several examples of odor removal or reduction by aeration have been observed. In one case, new harvest wheat was received in July and stored in a 45,000-bushel bin at an average temperature of 104° F. After 6 months with no turning or aeration, storage odors indicative of unsound grain were detected. After two mixing turns in January, storage odors were still appreciable. In April the wheat was turned into an aerated bin. A composite sample taken at this time showed 12.3 percent moisture and the continued presence of storage odors. After the April turn, outside air was pulled through the grain for 145 hours of fan operation at an airflow rate of $\frac{1}{25}$ cfm per bushel. During loadout in May, the grain odor had improved and the official grade was No. 1 Dark Hard Winter Wheat.

Operating requirements for odor removal vary with the grain and storage conditions. Some odors can be dissipated by moving outside air through the grain for a few hours with fans controlled manually. Other odors may be removed by regular cooling.

A regular schedule for inspection of grain in long-term storage may include odor detection. Fans are operated 30 minutes to 1 hour every 2 to 4 weeks. Odors detected at the fan exhaust are an indication of grain quality in the bin. At the same time, the replacement of air in the grain with outside air will minimize the development of odors.

APPLYING FUMIGANTS

Aeration systems are used to apply fumigants in many storages (*5, 6, 7, 8*). Aeration distributes the fumigant rapidly and in some cases requires less fumigant than other application methods.

Aeration systems are manually operated for application of fumigants. Fans are operated from a few minutes to a few hours depending upon the method utilized. The fan operation time required to distribute fumigants is not long enough to produce significant changes in grain temperature or moisture. Certain types of fumigants are exhausted from the grain after a selected exposure period by operating the fans a short time.

Upright storages can be fumigated by two methods—single pass and recirculation. In the single-pass method, the fans are operated long enough for a single air change; for example, 10 minutes at $\frac{1}{20}$ cfm per bushel or 20 minutes at $\frac{1}{40}$ cfm per bushel. The entire fumigant dosage may be applied to the surface of the grain if the air is moved downward. When air is moved upward, the fumigant is metered into the airstream uniformly during the time the fan is operated.

In the recirculation method for upright storages, the fumigant is moved through the grain several times. A return duct is used with many systems. Some manifold systems and portable fan systems can recirculate the fumigant by moving it down through one bin and up through another.

A flat storage cannot easily be completely fumigated by the single-pass method because airflow is not uniform through the grain. Single-pass application combined with gravity penetration, or gravity penetration alone, has been used.

The recirculation method is frequently used in flat storages. A tight building and a return duct are required. Ventilators, eaves, door joints, and other openings must be sealed to prevent excess leakage. Distribution of the fumigant usually can be improved by attaching fans to move air upward through the grain (see section on Direction of Airflow). Additional fumigant may be

applied to the top surface after recirculation to aid insect control. Bin walls may be treated with approved insecticide to kill escaping insects and prevent reinfestation.

Some flat storage operators use various fumigants, insecticides, and grain protectants for periodic surface treatment of grain. The treatments help to control insects and reduce the number of complete fumigations required.

Grain may be cooled enough by normal aeration schedules to suppress insect activity. Optimum grain temperatures, 35° to 50° F., resulting from winter aeration have been effective in preventing increase of insect population in upright storage bins under test. With summer-harvested wheat, cooling does not replace all fumigation. One fumigation shortly after harvest is desirable, but a second fumigation is not usually needed if all the wheat is cooled to temperatures below 50° F. during the winter.

HIGH-MOISTURE LAYER IN THE GRAIN MASS

Grain should be mixed or blended before long-term storage with aeration. Layers or large pockets of wet grain may result in loss of quality. Although the average moisture content of a bin of grain may be below the safe storage limit, a high-moisture area can cause storage problems.

In one test, aeration failed to remove a high-moisture layer of grain. Wheat was loaded into an upright storage bin 105 feet deep with a capacity of 47,000 bushels. The bottom 85 feet of wheat had from 11.0 to 11.7 percent of moisture. Then a 15-foot layer with 13.1 percent of moisture was loaded into the bin, with about 4 feet of wheat with 11.7 percent moisture at the surface. The initial composite sample tested 11.9 percent moisture and the ending composite sample was 11.4 percent moisture. During the summer stage of aeration at 1/25 cfm per bushel for 232 hours of fan operation, the average grain temperature was reduced from 98° to 84° F. The second cooling stage, with 426 hours of fan operation between November 14 and December 23, reduced the grain temperature from 80° to 44° F. After the winter aeration, probe samples in the moist layer still tested about 12.8 percent moisture.

On the other hand, aeration may help to (1) equalize the moisture of well-blended grain of different moisture levels or (2) distribute moisture from small areas of wet grain. In one upright storage test, a lot of wheat at 16 percent moisture was blended with another lot at 11 percent moisture during turning into an aerated bin, with a resulting average moisture content of 12.8 percent. The initial grain temperature was 97° F. The storage period was 3 months with aeration in the summer and fall. The final average grain temperature was 68° F. and the final moisture content was 12.3 percent. Probe samples in the surface area and bag samples through the depth of the bin showed uniform moistures and no grain deterioration.

WARMING GRAIN

It is possible to warm grain by aeration in the spring and summer. However, warming may increase grain moisture and cause storage problems unless proper procedures are followed. Warming grain is not recommended as a regular practice in the Hard Winter Wheat area.

Warming grain by aeration has been suggested by operators as a method of (1) controlling occasional hot spots that develop in the spring and summer, (2) permitting effective fumigation, and (3) correcting moisture accumulations discovered in warm weather. Moisture accumulations have been reported from 1 to 5 feet below the surface in both upright and flat storages. Most of the limited reports have originated from experiences with shelled corn storages.

Possible causes of moisture buildup in the surface area in warm weather include (1) improper winter aeration—cooling grain to very low temperatures or using air of relative humidity above 80 percent, (2) normal movement of warm moist air over and through cold surface grain causing condensation, and (3) moisture migration within the grain mass. In test bins, slight moisture increases have been found in the grain layer 1 to 3 feet below the surface. We believe this was a result of warm air penetrating the surface layer, contacting cold grain and depositing moisture. The increase has not been sufficient to cause a storage problem in wheat bins. This type of moisture increase occurs more readily in shelled corn storages where air can move more freely through the surface layers of grain.

It is suggested that frequent inspections be scheduled in spring and summer to detect any buildup of surface moisture. Only when moistures above safe storage level are found and storage problems are imminent should aeration for warming be considered.

One hazard of warming grain was demonstrated by a laboratory test (*3*). Shelled corn was ventilated with a large volume of air at a high relative humidity. Moisture increased from 13 percent to an average of 15.1 percent (range 13.4 to 16.9 percent). Stresses in the sidewalls of a deep bin were increased to at least six times that of dry grain. Such stresses could exceed the ultimate load limit for a grain storage structure.

Another hazard of warming grain by aeration is the possibility of increased grain moisture at the warming front. As the grain warms, the air is cooled and its relative humidity is increased. Grain moisture may then increase if the warming front is not moved on through the bin, particularly if a marked difference in grain temperature exists above and below the warming front. For this

reason, once a warming front is started through a bin of grain, aeration should be continued until all of the grain has been warmed.

A limit on the relative humidity of the air introduced at the surface of the grain is important in a warming operation. After a warming front has passed, the surface grain will tend toward moisture equilibrium with the incoming air. Air below 70 percent relative humidity has been used successfully in warming tests. A relative humidity limit of 80 percent was used in one test of early spring aeration. The surface foot of grain increased in moisture from 12 percent to 14 percent. Lesser moisture increases were noted down to the 5-foot level. During aeration the surface grain was warmed from 35° to 48° F.

A special test was conducted in a bin of relatively dry wheat at 10.5 percent initial moisture. The wheat was warmed from 46° to 58° F. during March and April using air above 50° F. and below 70 percent relative humidity. During June the wheat was warmed from 58° to 77° F. using air above 65° F. and below 75 percent relative humidity. Moisture changes based on probe samples showed a decrease in the top 8 feet and an increase between the 9- and 15-foot depths. No probes were obtained below the 15-foot depth. The maximum increase in moisture for any probe sample was three-fourths of 1 percent. A composite sample after the test showed an increase to 10.8 percent moisture.

MOVING COLD GRAIN DURING WARM WEATHER

Moving cold grain, below 50° F., during warm weather may result in condensation and increased grain moistures. Sweating of bin draw-offs and handling equipment in contact with cold grain has been observed. This suggests that similar condensation occurs on the surface of cold grain as it leaves a bin. However, surface moisture may easily be released to the air during further handling. There have been no reports from the Hard Winter Wheat area of difficulty in moving grain during warm weather when the grain was not cooler than 35° F. The use of low-limit temperature settings will prevent cooling grain to very low temperatures.

DIRECTION OF AIRFLOW

Air is normally moved downward through grain during aeration. This is done primarily for two reasons: (1) downward movement counteracts the natural tendency of convection currents to move upward from warm grain to cold surface grain where condensation may occur, and (2) the exhaust air, usually warm and moist, is expelled through warm grain in the lower part of the bin and not through the colder grain at the surface where moisture may accumulate.

Most aeration systems can be adapted for either upward or downward airflow for special situations such as nonuniform airflow or fumigation. Air can be moved upward by attaching the exhaust side of the fan to the supply pipe of the aeration duct. The quantity of air moved is about the same for upward or downward airflow.

Upward airflow can be used in some flat storages to counteract nonuniform airflow caused by long ducts of small cross section. In suction systems, the grain at the end of the aeration duct furthest from the fan receives the least airflow. Moving air upward reduces the nonuniformity by converting velocity pressure to static pressure as the air moves along the duct from the fan to the opposite end. Upward air movement may be preferable in flat storages where airflow is extremely nonuniform. However, condensation may occur as the warm air contacts cold air at the grain surface and at the bin roof and walls. Increased supervision will be required with upward air movement.

In the fall, aerated grain carried in storage for a second year is warm at the surface and cool at the center of the storage. With upward airflow the surface grain could be cooled without pulling the warm air through the cool mass of grain below. Thus, cooling could be completed in a shorter time than with downward airflow. However, condensation might occur. The operation is not recommended in the Hard Winter Wheat area without continuous supervision.

USE OF TEMPERATURE-MEASURING EQUIPMENT

Many commercial grain storage operators have installed temperature-measuring equipment in the grain. The progress of a cooling zone through a bin of grain can be traced by taking frequent temperature readings. The completion of a cooling stage can be determined.

Another method of determining completion of cooling is the use of a thermometer, such as an all-metal dial thermometer, in the air exhaust from a bin of grain. A thermometer is used for each aeration duct. Exhaust air temperatures are recorded daily while the fan is operating. Cooling is completed when exhaust air temperatures approach the average outside air temperature.

With either method of checking the completion of cooling, additional cooling time should be allowed after selected temperature readings have been obtained. This will permit the completion of cooling in areas of low airflow in a part of the bin away from the temperature cable, cooling grain at bin walls in contact with adjoining warm grain, and other nonuniform cooling. In upright storage an additional 10 percent operating time over the basic time (table 1) is allowed (table 4).

For flat storages, location of temperature cables in relation to the aeration ducts must be considered. Temperature cables directly over the

ducts will be the first to show cooling; those between ducts and at the greatest grain depth will more accurately indicate the completion of cooling. Time allowed for cooling in flat storages (table 5) is double the basic time.

Grain temperature readings other than those taken during aeration are used to indicate quality maintenance during storage. Grain temperatures taken during aeration may not be a reliable indication of quality because aeration may remove heat due to mold and insects. An increase in grain temperature after aeration is completed usually indicates moisture accumulation, grain deterioration, or insect development.

PROVISIONS FOR ENTRANCE OF OUTSIDE AIR

Outside air must enter the bin through roof ventilators, wall ventilators, or bin fill holes, when aeration fans are operating. The area of the opening should be at least twice the cross-sectional area of the supply pipe between the fan and aeration duct. Ventilators not continuously open should be opened automatically whenever fans are operating. Protection from weather must be considered. In upright storages where bin fill holes are in an enclosed gallery above the bins, arrangements should be made for outside air to enter through ventilators or windows. When fans are inoperative, free circulation of air usually is allowed over the grain surface.

Supply pipes leading to aeration ducts should be sealed by slide gates, supply pipe caps, or dampers when fans are inoperative for a considerable length of time. Free circulation of moist air may increase the moisture in grain around the aeration duct, particularly warm air coming in contact with cold grain. Supply pipes need not be closed when fans are inoperative during an aeration stage.

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APPENDIX

Table 6.—*Hours available at specified control limits for operating aeration fans in grain storages, Wichita, Kans., 1950–59* [1]

Control limits			Average 1950–59	Maximum	Minimum
Temperature		Relative humidity (high limit)			
High limit	Low limit				
°*F.*	°*F.*	*Percent*	*Hours*	*Hours*	*Hours*
JULY					
90	--------	90	515	596	381
85	--------	90	420	529	264
80	--------	90	295	431	127
AUGUST					
90	--------	90	555	645	484
85	--------	90	453	522	379
80	--------	90	324	392	224
SEPTEMBER					
75	--------	90	375	443	294
70	--------	90	255	324	170
65	--------	90	153	220	71
75	--------	80	300	406	207
70	--------	80	191	296	122
65	--------	80	111	155	62
OCTOBER					
70	--------	90	497	629	424
65	--------	90	417	555	307
60	--------	90	319	459	182
70	--------	80	404	626	296
65	--------	80	331	552	248
60	--------	80	244	456	143
NOVEMBER					
65	--------	90	608	683	530
60	--------	90	571	649	497
55	--------	90	516	600	435
50	--------	90	443	539	345
65	--------	80	517	649	316
60	--------	80	483	615	309
55	--------	80	431	573	289
50	30	80	284	370	217
50	20	80	348	459	238
50	--------	80	365	513	238
DECEMBER					
50	30	80	320	396	254
50	25	80	378	490	318
50	20	80	414	503	333
50	--------	80	456	596	340
45	30	80	265	341	200
45	25	80	323	428	263
45	20	80	359	451	289
45	--------	80	422	550	348

Table 6.—*Hours available at specified control limits for operating aeration fans in grain storages, Wichita, Kans., 1950–59* [1]—Continued

Control limits			Average 1950–59	Maximum	Minimum
Temperature		Relative humidity (high limit)			
High limit	Low limit				
°*F.*	°*F.*	*Percent*	*Hours*	*Hours*	*Hours*
JANUARY					
50	30	80	237	332	128
50	25	80	282	395	189
50	20	80	327	428	249
50	--------	80	433	530	327
45	30	80	196	270	108
45	25	80	238	333	169
45	20	80	283	366	221
45	--------	80	389	471	255
FEBRUARY					
50	30	80	225	329	86
50	25	80	258	352	151
50	20	80	294	366	193
50	--------	80	333	423	257
45	30	80	173	265	76
45	25	80	206	288	118
45	20	80	241	317	145
45	--------	80	281	369	201
MARCH					
60	--------	80	451	576	299
55	--------	80	403	532	286
50	--------	80	331	440	210
APRIL					
70	--------	80	433	510	269
65	--------	80	376	465	221
60	--------	80	314	417	181
MAY					
75	--------	80	345	448	247
70	--------	80	255	341	166
65	--------	80	165	265	96
JUNE					
90	--------	90	545	599	494
85	--------	90	470	559	387
80	--------	90	363	473	245

[1] Compiled from Local Climatological Data, Monthly Supplement, U.S. Dept. of Commerce, Weather Bureau.

Table 7.—*Hours available at specified control limits for operating aeration fans in grain storages in the Hard Winter Wheat area, based on weather data for 10-year period, 1950–59*

Months	Control limits			Time available for fan operation											
	Temperature		Relative humidity (high limit)	Kansas City		Wichita		Oklahoma City		Amarillo		Denver		Omaha	
	High limit	Low limit		Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.
	°F	*°F.*	*Percent*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
July	85	--------	90	456	316	420	264	385	331	485	410	607	546	487	385
Aug	85	--------	90	477	398	453	379	405	343	500	447	639	603	501	444
Sept	70	--------	90	274	202	255	170	180	107	303	242	468	442	349	307
Oct	70	--------	90	520	427	497	424	448	412	514	450	609	544	557	476
	50	30	80	308	203	284	217	253	196	307	208	344	255	300	246
Nov	50	20	80	382	269	348	238	296	214	366	242	428	350	389	325
	50	--------	80	402	280	365	238	301	214	384	259	476	391	437	340
	50	30	80	323	199	320	254	325	219	374	286	370	303	242	115
Dec	50	20	80	427	284	414	333	377	256	477	416	512	431	357	199
	50	--------	80	494	335	456	340	398	256	505	416	573	496	467	220
	50	30	80	232	138	237	128	241	118	321	275	328	222	144	69
Jan	50	20	80	352	278	327	249	321	196	412	322	479	383	267	172
	50	--------	80	494	373	433	327	363	257	469	322	596	534	498	208
	50	30	80	238	103	225	86	224	148	266	149	307	243	196	55
Feb	50	20	80	321	167	294	193	265	170	321	195	415	358	279	125
	50	--------	80	385	285	333	257	276	170	341	195	475	400	396	265

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U.S. GOVERNMENT PRINTING OFFICE: 1961 O—600254